Response to the reviewers

Dear Reviewer:

Thank you for your comments. These are all valuable and very helpful for revising and improving our paper, as well as the important guiding significance to our researches. We have studied comments carefully and responded to them which are described in detail below.

For the question that needs to be clarified is what is the value of the meta model compared to the many load surrogate models that are available in the literature, our specific explanation is below.

Thank you for your comment. The Meta mode mentioned in this paper is constructed based on MLP (Multi-layer Perceptron), which essentially focuses on its ability to capture complex nonlinear relationships, provide reliable results, and reduce the number of training samples. Compared to the traditional load surrogate models (Linear Regression, Polynomial Regression, Gaussian Process and Response Surface Regression), it performs better when dealing with complex systems, especially when data and computational resources are limited. In fact, we have also used the above method to try to compare and selected MLP based on the accuracy of the results, but we have not expressed it in the paper due to space limitation.

However, the optimal approach must be determined based on the specific application scenario, data characteristics, and available computational resources [1]. Future research should further investigate the potential of multi-fidelity data fusion and deep learning techniques to improve model accuracy and robustness.

References：

[1] Angione C, Silverman E, Yaneske E，(2022) Using machine learning as a surrogate model for agent-based simulations. PLoS ONE，17(2): e0263150.

- **Comment No.1:** when comparing the time saving, how would the authors account the time and efforts needed to produce the data needed to train the meta model. since this would be necessary each time the turbine model or turbine properties have been changes, which is often the case in the design iteration phase. Normally the 50 years return value for extreme load is a design value based on generic wind class or site specific value for certain class of sites, for example typhoon or hurricane affected area. It is usually not needed to perform load extrapolation for each of the wind turbine in a wind farm. Once it has been identified which turbine in the wind farm has the highest extreme loads, one needs only to perform the load extrapolation for the worst case. It is rather unlikely that optimization for extreme loads will be performed for every single turbine. Moreover, it is not clear from the beginning of the design, whether fatigue or extreme load will be the design driver. Therefore, the usefulness and time saving should be considered with these points in mind.

Response 1: Thank you for your comment. The load extrapolation methods mentioned in this paper are mainly used for site suitability assessment and will not be used for iteration in WTG development and design. Here is a more specific explanation.

1. The model used for generating the load simulation database is either a finalized model or a wind turbine model that has obtained DA/TC certification.

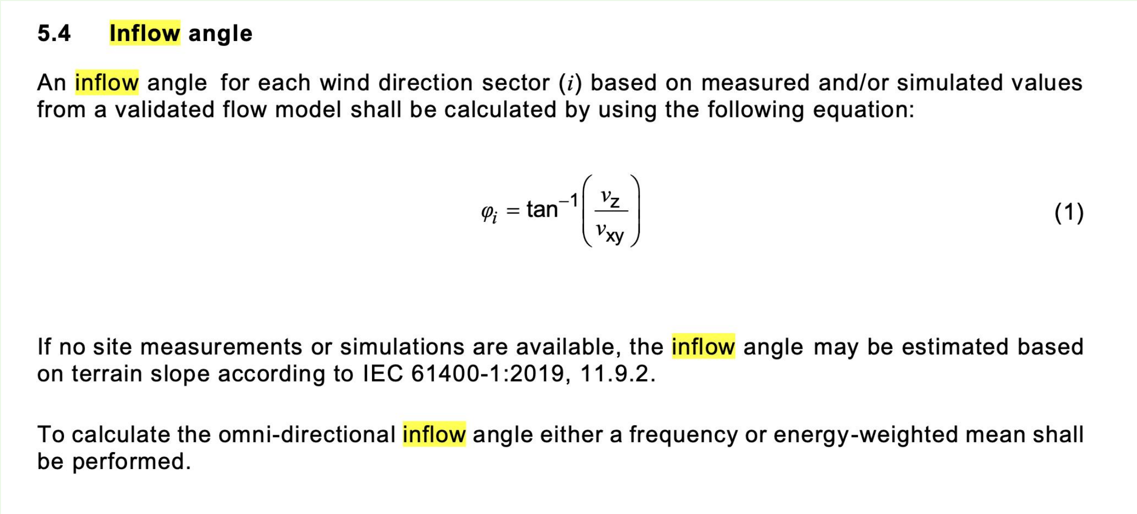
2. According to IEC 61400-1:2019 Annex B, for site suitability assessment, the following ultimate design load cases shall be assessed as minimum: DLC 1.1, DLC 1.3, DLC 6.1, and DLC 6.2. If the design load cases for the standard classes are adequate, no further evaluations need to be performed. The DLC1.1 is also required for site-specific calculations. The “adequate” scenario is only qualitatively described in the standard, it is often difficult to prove it to an independent third-party certification body during the SSDA certification process, so it is necessary to perform the DLC1.1 for site-specific projects.

3. The worst case is a common practice in previous years, but nowadays it has become a mainstream trend to strike a balance between economy and conservatism, so wind turbines in wind farms with complex terrain are usually divided into groups to replace the worst case. With the rapid development of the wind power industry, a top OEM will do at least a thousand wind farm site suitability assessments per year, and the amount of computation and time required for the DLC1.1 is very large. In addition, it is the probability density of each wind speed bin and the corresponding turbulence intensity that plays a role in the DLC1.1 case, the worst case is extremely conservative in some cases, which is a common situation in China. And when doing SSDA certification, the independent third-party certification bodies usually require proof of the vague description of the worst case. Using the methodology mentioned in this paper, each turbine can be quickly evaluated to determine the worst case, and then using Bladed/FAST/HAWC2 can be performed, which is a common practice in the industry.

In summary, the proposed FASTLE method demonstrates significant potential for site-specific preliminary load assessment, grouping, and worst-case selection. Moreover, it offers substantial reductions in computational cost and processing time compared to conventional approaches.

- **Comment No.2:** In page three, line 84, the word inflow angle is mentioned. In this case, it is referred to the yaw angle between the rotor plane with the incoming wind, that is, the yaw misalignment angle, if the reviewer understands it correctly. Inflow angle is used in the aerodynamics mainly for the angle of the velocity triangle at the airfoil, between the tangential velocity caused by the rotation of the rotor and the incoming wind velocity. The use of the word inflow angle can cause some confusion as this is not used normally in this context.

Response 2: Thank you for your comment. The inflow angle referenced in this paper is derived from IEC 61400-15-1:2025 (Section 5.4) and illustrated in Fig. 1. It is critical to note that this parameter does not represent the yaw misalignment angle but aligns with the definition of flow inclination as specified in IEC 61400-1:2019. While DNV-ST-0473 also employs inflow angle to describe flow inclination, this usage may lead to ambiguity with the inflow angle defined in Blade Element Momentum (BEM) theory. To avoid confusion, we will either provide a detailed clarification or adopt the flow inclination consistently throughout the paper.



5.4 Inflow angle

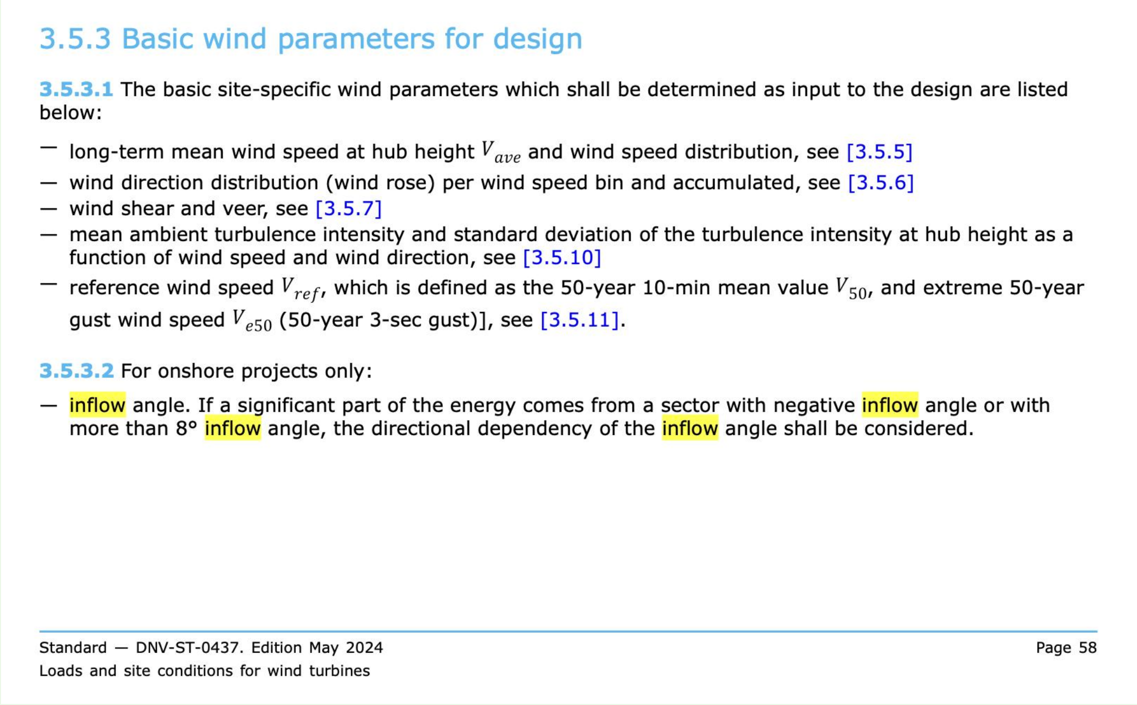
An inflow angle for each wind direction sector (i) based on measured and/or simulated values from a validated flow model shall be calculated by using the following equation:

$$\varphi_i = \tan^{-1}\left(\frac{v_z}{v_{xy}}\right) \quad (1)$$

If no site measurements or simulations are available, the inflow angle may be estimated based on terrain slope according to IEC 61400-1:2019, 11.9.2.

To calculate the omni-directional inflow angle either a frequency or energy-weighted mean shall be performed.

Fig. 1 IEC 61400-15-1:2025 chapter 5.4



3.5.3 Basic wind parameters for design

3.5.3.1 The basic site-specific wind parameters which shall be determined as input to the design are listed below:

- long-term mean wind speed at hub height V_{ave} and wind speed distribution, see [3.5.5]
- wind direction distribution (wind rose) per wind speed bin and accumulated, see [3.5.6]
- wind shear and veer, see [3.5.7]
- mean ambient turbulence intensity and standard deviation of the turbulence intensity at hub height as a function of wind speed and wind direction, see [3.5.10]
- reference wind speed V_{ref}, which is defined as the 50-year 10-min mean value V_{50}, and extreme 50-year gust wind speed V_{e50} (50-year 3-sec gust)], see [3.5.11].

3.5.3.2 For onshore projects only:

- inflow angle. If a significant part of the energy comes from a sector with negative inflow angle or with more than 8° inflow angle, the directional dependency of the inflow angle shall be considered.

Standard — DNV-ST-0437. Edition May 2024 Page 58
Loads and site conditions for wind turbines

Fig. 2 DNV-ST-0473

- **Comment No.3:** Page 4. which is the shear model used and how is the shear value defined, please elaborate.

Response 3: Thank you for your comment. The power-law shear profile is used model in this paper. We will add a description to the paper.

- **Comment No.4:** Figure1, the distribution of the air density looks bi-modal, when sampling the distribution, did the authors take the empirical distribution or the fitted bi-modal distribution?

Response 4: Thank you for your comment. The air density distribution is obtained using the Kernel Smoothing method based on a large amount of test data, the reference is as follow.

Reference:

[2] M. P. Wand & M. C. Jones Kernel Smoothing Monographs on Statistics and Applied Probability Chapman & Hall, 1995.

- **Comment No.5:** Table 1 why is the inflow angle changes from -0.78 to 13.464 degrees (there is no need to go beyond the first digit for this angle, the turbine yaw controller is not that precise) , what about the variation in the negative angle. the loading on the wind turbine is not symmetrical around the yaw angle, negative and positive yaw angles can produce very different loads.

Response 5: Thank you for your comment. In fact, for yaw misalignment angle setting, this paper uses equal numbers -8, 0, 8 . The inflow angle here refers to the flow inclination.

- **Comment No.6:** Table 2 change RMP to RPM.

Response 6: Thank you for your comment. We have made changes in the manuscript.

- **Comment No.7:** Page 7 what is the definition of In plane and out of plane bending moment here. It looks like the authors is using the flapwise bending moment and not the out of plane bending moment of the blade. Once the blade starts pitching after reaching the rated wind speed, the the OOP bending moment and flapwise bending moment are no longer the same.

Response 7: Thank you for your comment. In this paper we used the blade coordinate system from the GL2012, as shown in Fig. 3. The MYB is out of plane bending moment and MXB is in plane bending moment, which will be described in detail later in the paper.

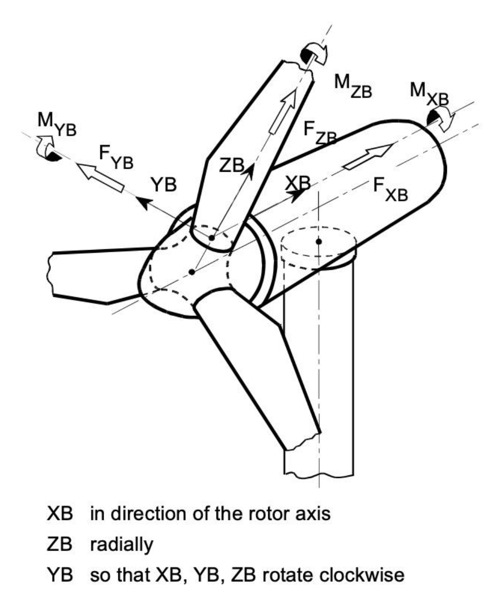


Fig. 3 Coordinate system

- **Comment No.8:** Equation 6, this equation assumes that the 10 minutes wind speeds are independent, which is clearly not the case.

Response 8: Thank you for your comment. The equation 6 is the calculation of the exceedance probability of the 50-year extreme load. The probability of the 50-year load is approximately 3.8×10^{-7}, is consistent with the definition in IEC 61400-1:2019.

- **Comment No.9:** Page 9, line 171, the authors divided the data into three categories, high wind speed range above 10 m/s , low wind speed range below 10 m/s and full wind speed range, which wind speed would be full wind speed range have?

Response 9: Thank you for your comment. The full wind speed means Cut-in wind speed to cut-out wind speed, which includes 2.5m/s～24m/s.

- **Comment No.10:** Figure 6 why are the log-normal performed so poorly in QQ plot?

Response 10: Thank you for your comment. The distribution of the extracted peak loads at a certain wind speed does not obey the log-normal distribution, which is confirmed by using the Chi-Squared test and the Kolmogorov -Smirnov goodness-offit test to test the log-normal. Therefore, when QQ-plot was used to visualize the presentation, the log-normal performance was not good as shown in Figure 6. In fact, at that time, when we used openturns (python package) to do distribution fitting work and got very poor log-normal distribution fitting results, we used the same data and switched to scipy (python package) to do log-normal fitting and Chi-Squared test, and found that the results did not change.

- **Comment No.11:** Table 3, there is not need to have numbers with 9 digits after the decimal point, there are a lot of uncertainties.

Response 11: Thank you for your comment. We have made changes in the manuscript. All relevant numbers are retained to 4 digits.

- **Comment No.11:** Figure 10, how ar ehte importance of the hyperparameters determined?

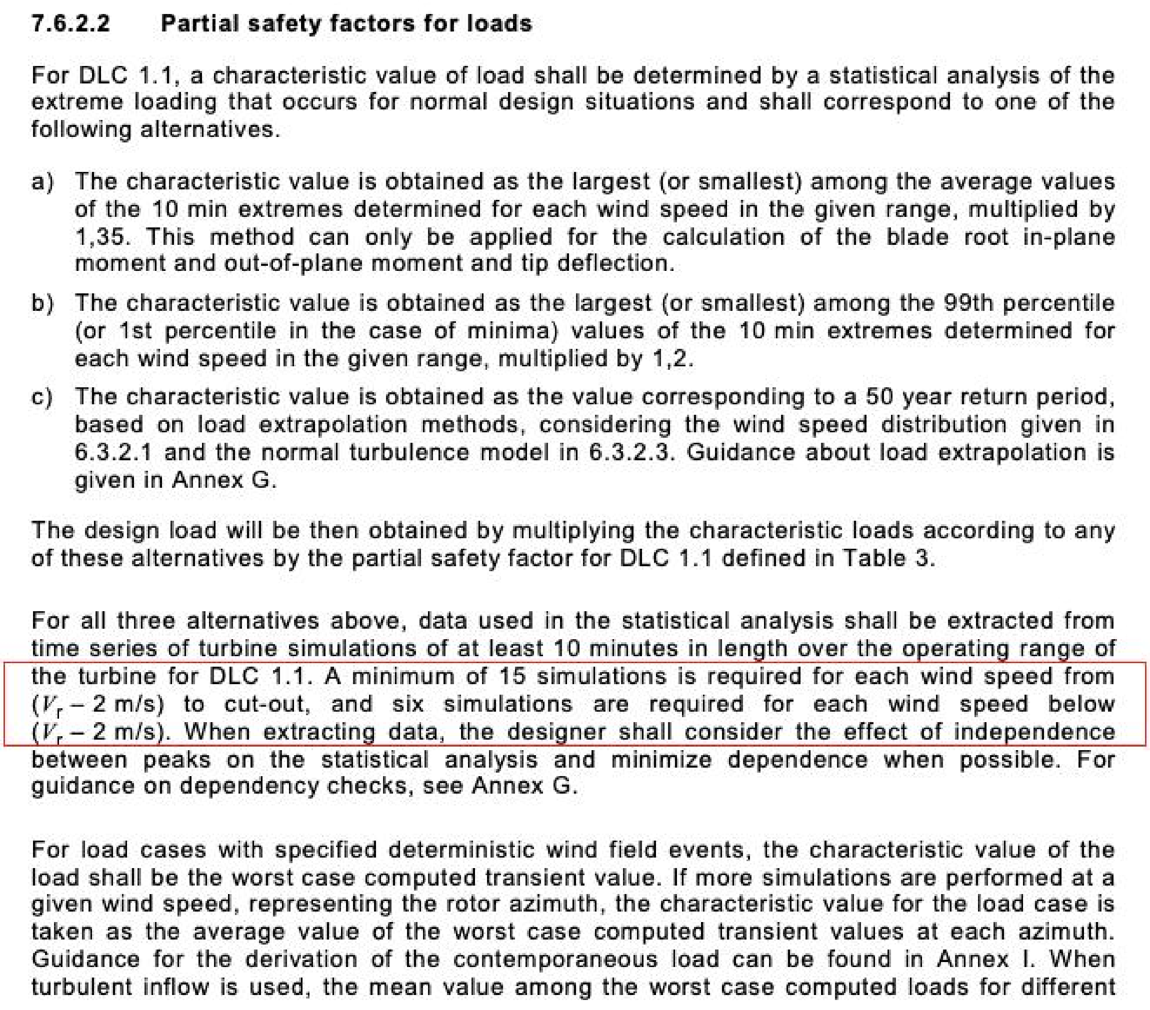
Response 11: Thank you for your comment. Based on the Optuna (python package) using Fanova Importance Evaluator to implement it, see reference for a description of the methodology.

Reference:

[3] Frank H, Holger H, Kevin L. An Efficient Approach for Assessing Hyperparameter Importance, Proceedings of the 31st International Conference on Machine Learning, PMLR 32(1): 754-762, 2014.

- **Comment No.12:** Page 9 line 176, so if the low wind speeds contribute so little to the tail of the distribution, then why simulate them at all.

Response 12: Thank you for your comment. According to the practical experience, the low wind speed contributes extremely little to the 50-year extreme load extrapolation, but it does not mean that there is none at all. and the IEC 61400-1:2019 (Section 7.6.2.2) has made a requirement for the simulation of low wind speeds, as shown in fig. 4, so this paper also carries out the simulation analysis of low wind speeds.



7.6.2.2 Partial safety factors for loads

For DLC 1.1, a characteristic value of load shall be determined by a statistical analysis of the extreme loading that occurs for normal design situations and shall correspond to one of the following alternatives.

a) The characteristic value is obtained as the largest (or smallest) among the average values of the 10 min extremes determined for each wind speed in the given range, multiplied by 1,35. This method can only be applied for the calculation of the blade root in-plane moment and out-of-plane moment and tip deflection.

b) The characteristic value is obtained as the largest (or smallest) among the 99th percentile (or 1st percentile in the case of minima) values of the 10 min extremes determined for each wind speed in the given range, multiplied by 1,2.

c) The characteristic value is obtained as the value corresponding to a 50 year return period, based on load extrapolation methods, considering the wind speed distribution given in 6.3.2.1 and the normal turbulence model in 6.3.2.3. Guidance about load extrapolation is given in Annex G.

The design load will be then obtained by multiplying the characteristic loads according to any of these alternatives by the partial safety factor for DLC 1.1 defined in Table 3.

For all three alternatives above, data used in the statistical analysis shall be extracted from time series of turbine simulations of at least 10 minutes in length over the operating range of the turbine for DLC 1.1. A minimum of 15 simulations is required for each wind speed from (V_r – 2 m/s) to cut-out, and six simulations are required for each wind speed below (V_r – 2 m/s). When extracting data, the designer shall consider the effect of independence between peaks on the statistical analysis and minimize dependence when possible. For guidance on dependency checks, see Annex G.

For load cases with specified deterministic wind field events, the characteristic value of the load shall be the worst case computed transient value. If more simulations are performed at a given wind speed, representing the rotor azimuth, the characteristic value for the load case is taken as the average value of the worst case computed transient values at each azimuth. Guidance for the derivation of the contemporaneous load can be found in Annex I. When turbulent inflow is used, the mean value among the worst case computed loads for different

Fig. 4 IEC 61400-1:2019 (Section 7.6.2.2)

- **Comment No.13:** Instead of local distribution, maybe it is better to refer them as local maxima, or local peaks distribution.

Response 13: Thank you for your comment. We will be changed to local peaks distribution.

- **Comment No.14:** Table 5, the simulation time is 600seconds, what about the transient at the beginning of the simulation, are they removed?

Response 14: Thank you for your comment. In fact, when bladed was used for the simulation, the simulation duration was set to 650 seconds, and the latter 600 seconds was used for the data output, which will be supplemented in the paper.

Once again, thank you very much for the constructive comments and suggestions which would help us in depth to improve the quality of the manuscript. We will try our best to improve the manuscript. Please feel free to contacts with any questions.

Kind regards,

Pengfei Zhang